Evaluation of the Maths Arcade initiative at five U.K. universities

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Published version

ROWLETT, Peter, WEBSTER, Kingsley, BRADSHAW, Noel-Ann and HIND, James (2017). Evaluation of the Maths Arcade initiative at five U.K. universities. The Mathematics Enthusiast. (In Press)

Evaluation of the Maths Arcade initiative at five U.K. universities

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Abstract
The Maths Arcade is a regular, optional drop-in session to play strategy games and puzzles, taking place at a range of U.K. universities. The main aims are to support students, create a maths-themed staff-student community and develop mathematical thinking through strategy game-play. At some universities, the Maths Arcade has additional aims, including motivating curricular work, linking to peer assisted learning and promoting cross-disciplinary interaction.

The games used are strategy games with simple rules which have no explicit link to mathematics but appeal to logical thinking. The games and activities typically used at a Maths Arcade are described and an example of a deep investigation is given as a case study.

An evaluation of the Maths Arcade at five U.K. universities was completed by distributing a questionnaire to attenders and non-attenders. Students who attend more sessions were more likely to report making friends at the Arcade, and a majority of students said that staff presence is helpful and they would like staff to attend more often, results which support the aim of creating a mathematical community. Students report liking the games, and those who attend more often are more likely to prefer games that are more open to analysis, supporting the aim to develop mathematical thinking through analysis of gameplay. Negative feedback focused mostly on practicalities, including quality of advertising and scheduling of Maths Arcade sessions.

1. Introduction
The Maths Arcade is a regular drop-in session to play strategy games and puzzles, offering an informal support mechanism, the chance to develop a staff-student mathematics-themed community and the opportunity to develop mathematical thinking. This article describes the Maths Arcade and its implementation at several UK universities, and details the results of an evaluation via survey of students at five universities running Maths Arcades.

2. About the Maths Arcade
The Maths Arcade aims to support struggling learners and stretch more confident learners by developing mathematical thinking and problem-solving skills through playing strategy games and tackling puzzles, while providing an opportunity for staff and students to interact together in a social, mathematics-themed extra-curricular environment. Typically, a weekly drop in session is offered where a variety of strategy games and puzzles are available for students to play with each other and members of staff. These might be simply played, to develop a mathematical-themed social environment as an informal support mechanism for students, or strategies might be analysed, to develop students' mathematical thinking and stretch more confident learners. It can also be used to provide a focal point for maths students from different year groups getting together with members of staff and postgraduate students to learn from each other. Trowler and Trowler (2010) state that "interacting with staff has been shown to have a powerful impact on learning especially when it

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takes place outside of the classroom". It is this interaction that the Maths Arcade is keen to promote, and "encouraging more opportunities for staff/student interactions" is highlighted by Croft and Grove (2015) as an advantage of the Maths Arcade initiative in relation to enhancing student experience (p. 181).

The Maths Arcade was initiated by Bradshaw (2011) at the University of Greenwich in 2010, and was expanded to eight universities in 2012 as part of the National HE STEM Programme (Bradshaw and Rowlett, 2012). Further universities have received funding since then, via internal funds or funding from the Institute of Mathematics and its Applications (IMA); for example, a Maths Arcade was set up at Nottingham Trent University in 2013 as a staff/student collaborative partnership using IMA funding (Webster and Rowlett, 2013).

The initial Maths Arcade was designed to support students particularly at the transition between school or college and university. Whilst many students from other disciplines are keen to attend the sort of maths support sessions described by Lawson (2015) at Greenwich and elsewhere, at that time Greenwich mathematics students were observed to be reluctant to attend 'help sessions'. This was apparently due to a perception that these are for weaker students and a reluctance to identify themselves as such. The Maths Arcade was designed to provide a venue for mathematical talk, games and problem-solving, where students could get help from academic staff or peers. Sessions attracted both stronger and weaker students. Some attended to play games, while others attended to work through exercises and talk to staff. At some universities, the Maths Arcade is used for formal input into the curriculum. Badger et al. (2012) promote "puzzle-based learning" and report a positive influence on problem-solving ability, independent learning skills and motivation (p. 1), as well as creativity and modelling skills, particularly in group learning activities (p. 8). These skills are key to mathematics degree programmes (QAA, 2015).

Carpenter (2011), giving a student view, wrote about how attending the Greenwich Maths Arcade was "of enormous benefit to [him] both on an academic and social front" and how all maths students also benefited from "fun, enjoyment, queries, banter and a light hearted approach to all aspects of mathematics" (p. 30). Informal evaluation at Greenwich has been extremely positive (Bradshaw, 2011).

As new Maths Arcades were set up, each started with a slightly different implementation adapted to suit local circumstances; some case studies are given by Bradshaw and Rowlett (2012). For example, the activity at the University of Salford included a formal project in game theory (Chadwick, 2012), that at Sheffield Hallam University included a link to the peer assisted learning scheme (Cornock and Baxter, 2012) and that at the University of Bath had a focus on cross-discipline interaction and support (Cliffe et al., 2012).

2.1 Games used

The games are chosen as unintimidating activities which, to the uninitiated, do not obviously seem connected with maths. Most are relatively new (and commercially available) strategy games which have simple rules and can be played quickly, but which are likely to appeal to mathematicians. Well-known games of the right sort, such as Chess or Go, are best avoided in case prior knowledge by some students causes an imbalance of ability, or the appearance of such an imbalance. Also, a game of Chess can take a whole Maths Arcade session, while shorter games have a focus on repeated play to develop a strategy. Chess tends to be available, however, as some students are very keen to play it. Choice of games at different Arcades varies due to differing funding levels and local interest, but some of the most frequently purchased games include Hex, Solomon's Stones, Quixo, Quoridor, Quarto, Pentago and Pylos.

Hex is the classic game independently invented by Piet Hein and John Nash and popularised by Gardner (1959), in which two players take turns to play counters of their colour on a hexagonal grid, attempting to join two opposite edges with a continuous chain of their counters. Solomon's Stones is a two-player game similar to Nim's game, which was also popularised by Gardner (1959) and analysed by Conway (1976) in *On Numbers and Games*. Solomon's Stones uses a triangular arrangement of 28 stones. Players take it in turn to remove stones in the same row or column and try to avoid being the person who takes the last stone. Pylos involves building a pyramid of spheres, requiring three-dimensional thinking. Quoridor involves moving your piece across a chessboard while placing walls to obstruct your opponent. This is a game that those interested in programming particularly seem to enjoy. Pentago has similarities with noughts and crosses on a 6×6 board, but after each move, a quarter section of the board must be rotated, which can significantly change the position. Quixo, another noughts and crosses variant, involves sliding rows of blocks across a 5×5 board to form five in a row. Quarto, a game devised by Swiss mathematician Blaise Müller (Gough, 2015; p. 26), is described below.

2.2 Activities at the Maths Arcade

As an extra-curricular activity, the Maths Arcade does not involve formal attendance or pre-determined structure. Rather, it is a drop-in session where students choose activities in which to participate. New visitors generally enjoy learning to play unfamiliar games. However, as time passes attendees tend to start to think about strategy. Questions occur, such as what is the best strategy to maximise your chance of winning? Is there an advantage to making the first move? Is there a position on the board that is advantageous to capture? These questions can, prompted by staff or unprompted, lead to deep conversations and investigations. Some students discuss what would happen if the rules of a game were changed. Some use computers to investigate possible strategies. This is precisely the sort of investigation, building up mathematical skills, that the Maths Arcade aims to encourage. At its most advanced, the Maths Arcade has been used to motivate project work in game theory.

The following case study is designed to show some of the mathematical complexity which can be examined using a fairly simple game as a starting point.

Case study: Playing quarto on different sized boards

A Quarto board has sixteen spaces arranged in a 4×4 grid. Each game piece has four attributes taking one of two values, namely it is: tall or short; black or white; round or square; and, flat-topped or dimpled. Since each combination of attributes is used, this system uses $2^4 = 16$ pieces. Note that the number of pieces matches the number of spaces on the board.

Players take turns to choose an unplayed piece and hand it to their opponent, who places it in any unused space on the board. The player who places the fourth in a row, column or diagonal which all match any one attribute wins (i.e. four that are square, or four that are dimpled, etc.).

One of the authors and a student, speaking about how to extend noughts and crosses into Quarto, realised that we cannot play on an arbitrary-sized square board while maintaining the rule that the number of pieces equals the number of spaces on the board. Specifically, the counterexample discovered is that with three attributes and a 3×3 board, the size used for standard noughts and crosses, we cannot play; observe that $2^3 = 8 \neq 9 = 3^2$.

In general, then, for m attributes we have 2^m pieces and require this to be equal to the number of spaces on an n×n board. That is, $2^m = n^2$. Then we require $m = 2\log_2 n$. For a viable game (i.e.

integer m), we have that m is even and n is a power of 2. For example, six attributes uses 64 pieces on an 8×8 board, while fourteen attributes uses 16,384 pieces on a 128×128 board.

In fact, we can generalise so that pieces may take any number of attributes and boards can be made in higher dimensions. Then, a d dimensional board of side length n using pieces which have m attributes taking each of k values requires $k^m = n^d$, that is, $m = d \log_k n$. For example, four binary attributes on a 2×2×2×2 4-cube would use $2^4 = 2^4 = 16$ pieces, while 15 ternary attributes on an 27×27×27×27×27 5-cube would use $3^{15} = 27^5 = 14{,}348{,}907$ pieces. Setting $n = k^p$ to give $m = dp$ allows viable game configurations to be generated for positive integer p.

At Nottingham Trent University, students and staff have attempted to play Quarto on an 8×8 board and in 4 dimensions on a 2×2×2×2 board. The latter option can be played with the usual 16 Quarto pieces using a modification of a set of rules for 4-dimensional noughts and crosses (Butler, 2012). The 8×8 option requires a way to represent pieces with six attributes rather than the usual four. To do this, label each attribute either 0 or 1: white (0), black (1); short (0), tall (1); round (0), square (1); dimpled (0), flat-topped (1). Using a positional system in this order, the attributes for each piece in the game as sold are represented by a four-digit binary number. For example, 0100 would be white, tall, round and dimpled; 1001 would be black, short, round and flat-topped. The winning condition is met if four pieces in a line share one digit in common. For example, 0100 and 1001 are both round, and so both have third digit 0. Label each piece q_c where c is the decimal number representing the attributes. For standard Quarto, then, use $0 \leq c < 16$. Now, other board sizes can be assigned pieces using different length binary numbers. For example, six attributes uses $0 \leq c < 64$, while fourteen attributes uses $0 \leq c < 16384$. In practice, due to its complexity, 8×8 Quarto was played in correspondence mode via Twitter, with players taking turns to indicate the coordinates of a position on the board and the decimal number corresponding to the next piece to hand over. This method of labelling pieces enables their encoding in a computer program; an idea explored by Rowlett (2015).

3. Evaluation method

The evaluation was planned by participating universities at a meeting held at Sheffield Hallam University. The universities that returned data were Nottingham Trent University, University of Greenwich, University of Reading, Salford University and Sheffield Hallam University. A questionnaire was planned to collect students' perceptions about the Maths Arcade and its impact on their university experience, socially and academically, while providing some practical information for those running Arcades, such as around ideas for increasing attendance. Between the different universities, the Maths Arcades are operated in different ways, so the survey questions had to be sufficiently inclusive of these differences, while enabling a comparison between participating universities.

The intention was to hand out the questionnaire on paper during lectures, to maximise the number of replies and enable collection of data from non-attenders and those with infrequent attendance. Therefore, a question asked how often respondents attended the Maths Arcade, with options 'never', 'once', 'a few times' and 'most weeks'.

In fact, due to time constraints at the end of the academic year, two of the five universities were only able to distribute the questionnaire at a Maths Arcade session, reducing the presence of the non- and infrequent-attender voice in the data. The other three universities distributed questionnaires during lectures attended by a cross-section of attending and non-attending students. An online version of the questionnaire was considered, but it was felt this would attract fewer responses and making both available in parallel risked double-counting.

Practical questions aimed particularly at helping staff understand the running of their Arcade and how this might be improved included degree course, year of study and free-text questions 'What would encourage you to come to the Maths Arcade more often?', 'What is your favourite Maths Arcade game and why?' and 'What are the best and worst things about the Maths Arcade?'.

Questions aimed particularly at identifying students' views on the impact of the Maths Arcade on their university experience, aligned to the social aims of setting up a Maths Arcade (Bradshaw, 2011), were 'Have you made any new friends through the Maths Arcade?' (yes/no) and 'Do you think staff should attend the Maths Arcade more or less? Why?' (free-text).

4. Results

The questionnaire received 295 responses. By university, these were: Nottingham Trent University (101), University of Greenwich (72), University of Reading (102), Salford University (14) and Sheffield Hallam University (6). Of these, 124 were from students who had attended the Maths Arcade. By university: Nottingham Trent University (25), University of Greenwich (65), University of Reading (18), Salford University (12) and Sheffield Hallam University (6). A breakdown of responses by frequency in included in table 1.

Frequency	**Responses**
Most weeks	38 (13%)
A few times	56 (19%)
Once	30 (10%)
Never	169 (57%)
Unanswered	2 (1%)

Table 1: How often respondents attended the Maths Arcade.

From 124 students who had attended, 58 indicated that they had made friends at the Maths Arcade, 59 had not and seven did not answer the question. Table 2 gives a breakdown by attendance frequency, indicating that the students who attended more frequently more often made friends.

Attendance frequency	**Yes**	**No**
Most weeks	26 (70%)	11 (30%)
A few times	27 (51%)	26 (49%)
Once	5 (19%)	22 (81%)

Table 2: Whether students made friends at the Maths Arcade, by attendance frequency.

149 students answered the question about staff attendance, including 56 who had not indicated that they attend the Maths Arcade. Most students who answered said they would like staff to attend more often. A breakdown is given in table 3. For the seven who wanted staff to attend less often, only three had indicated that they had attended the Maths Arcade and the most common free-text response was that a student-only event would be less formal. For the 24 who suggested the same level of staff attendance, most did not give a reason but one indicated this was a choice for lecturers to make. The most common reasons for wanting staff to attend more were that this improves the staff-student relationship (37 responses) and that staff presence is helpful (33).

Staff attendance preference	**Responses**
More	118 (79%)
Less	7 (5%)
Same	24 (16%)

Table 3: Whether students wanted staff to attend more or less often.

The free-text question about what would encourage students to attend more often was answered by 209 students. These responses were grouped into categories, with some responses placed in more than one category, meaning that 235 responses are recorded. The data contains 101 reasons given by 88 students who indicated that they had attended the Maths Arcade and 134 reasons from 121 students who had not indicated that they had attended the Maths Arcade. A breakdown by attendance frequency is given in table 4.

The most frequent response was to highlight an issue with the timing of the Maths Arcade, usually either that this clashes with a sporting activity or that the gap between contact hours and the Arcade is so large that students do not stay at university for the Arcade. Responses to the question about the 'worse' things about the Maths Arcade also focused on these issues, with timetabling a particular issue.

Reason	**Most weeks**	**A few times**	**Once**	**Non-attenders**	**Total**
Different time	1 (4%)	14 (27%)	11 (42%)	33 (25%)	59 (25%)
Food	7 (29%)	8 (16%)	5 (19%)	32 (24%)	52 (22%)
Improved advertisement	0 (0%)	2 (4%)	3 (12%)	30 (22%)	35 (15%)
Different/more games	6 (25%)	7 (14%)	4 (15%)	6 (4%)	23 (10%)
Greater attendance level	2 (8%)	7 (14%)	2 (8%)	13 (10%)	24 (10%)
Help with academic work	3 (13%)	4 (8%)	0 (0%)	5 (4%)	12 (5%)
Competitions and other structured activities	0 (0%)	1 (2%)	0 (0%)	6 (4%)	7 (3%)
Incentives	1 (4%)	5 (10%)	0 (0%)	1 (1%)	7 (3%)
Other	4 (17%)	3 (6%)	1 (4%)	8 (6%)	16 (7%)

Table 4: Responses to 'What would encourage you to come to the Maths Arcade more often?'

Of those students who reported attending the Maths Arcade, 80 gave their favourite game; actually six of these gave two games, so that 86 responses are included. The most popular game overall was Quarto, with 11 out of 86 responses. The reasons given were mostly highlighting it as a challenging game. The numbers vary per university, however; for example, Ingenious is the most popular game at Sheffield Hallam University but does not feature in responses from any other university. Responses also vary according to attendance level. For example, Quarto was the most popular game among those attending 'most weeks' (9 responses), followed by Pentago (6 responses), while the most popular for those attending 'a few times' or 'once' was Blokus (10 responses), followed by Chess (7 responses). Chess is a game that is familiar to some students already. Blokus is a four-player game, meaning it may be easier for a group of friends to pick up and play even when they are not all frequent attenders.

The free-text question asking for the 'best' things about the Maths Arcade was answered by 76 students, all of whom had all attended the Maths Arcade, who gave 90 responses. The most common response was the games themselves, with 31 responses, and the social environment, with 19 responses.

5. Discussion

The Maths Arcade aims to support students, create a maths-themed staff-student community and develop mathematical thinking through strategy game-play.

The questionnaire attracted responses from students with a variety of attendance levels, giving confidence that the results represent different viewpoints. It should be noted that response rates varied per institution, with most attendee responses from University of Greenwich and most non-attendee responses from University of Reading.

The result that students who attended more frequently were more likely to make friends at the Maths Arcade is not surprising, but pleasing to see as building a mathematical community is one of the aims of the initiative. Almost three quarters of students would like to see more staff attendance, with many feeling this helps develop a staff-student community and that staff presence is helpful at the Arcade. Again this is pleasing as encouraging opportunities for staff/student interaction is one of the aims of the initiative.

Positives from the free-text feedback include students liking the games and enjoying the social environment. Negatives focused on practicalities, particularly the timing of sessions, and low attendance at some sessions. The former, finding a time that suits the different timetables for students in different year groups, is a difficult practical problem. Negotiation with those who arrange timetables gives the best chance of an amicable solution. The latter problem, students who are reluctant to attend because attendance is low, is difficult but ultimately self-fulfilling; hopefully if the timetable and advertising are well-organised, this problem will reduce.

Although numbers of responses were small, it is interesting to observe students who attend more frequently are drawn to the more challenging two-player games such as Quarto and Pentago than the four-player Blokus. As two-player games are more open to analysis, this promotes the idea that students may be moving from simply playing games towards analysis of strategy.

Funding

Webster's work on this project was funded by the Nottingham Trent University Scholarship Projects for Undergraduate Research (SPUR) scheme and supervised by Rowlett and Hind. An evaluation planning meeting was supported by Sheffield Hallam University.

References

Badger, M., Sangwin, C., Ventura-Medina, E. & Thomas, C.R. (2012). *A Guide to Puzzle-Based Learning in STEM Subjects*. Birmingham, U.K.: National HE STEM Programme.

Bradshaw, N. (2011) The University of Greenwich Maths Arcade. *MSOR Connections*, vol. 11(3), 26-29.

Bradshaw, N. & Rowlett, P. (Eds.) (2012). *Maths Arcade: stretching and supporting mathematical thinking*. Birmingham, U.K.: MSOR Network.

Butler, D. (2012). *4-Dimensional Noughts and Crosses*. Retrieved from https://www.adelaide.edu.au/mathslearning/play/4DOXRules.pdf

Carpenter, N. (2011). The University of Greenwich Maths Arcade – student view. *MSOR Connections*, vol. 11(3), 30.

Chadwick, E. (2012). University of Salford ‘Maths Arcade’ – As a project activity. In N. Bradshaw & P. Rowlett (Eds.), *Maths Arcade: stretching and supporting mathematical thinking* (p. 17). Birmingham, U.K.: MSOR Network.

Cliffe, E., White, J., Benjamin, L. & Lacey, C. (2012). University of Bath ‘MASH Café’ – Cross-disciplinary peer support and problem solving. In N. Bradshaw & P. Rowlett (Eds.), *Maths Arcade: stretching and supporting mathematical thinking* (p. 25). Birmingham, U.K.: MSOR Network.

Conway, J.H. (1976). *On Numbers and Games*. London, U.K.: Academic Press.

Cornock, C. & Baxter, E. (2012). Sheffield Hallam University ‘Maths Arcade’ – Feedback on a trial and plans to include in peer assisted learning. In N. Bradshaw & P. Rowlett (Eds.), *Maths Arcade: stretching and supporting mathematical thinking* (p. 19). Birmingham, U.K.: MSOR Network.

Croft, T. & Grove, M. (2015). Progression within the mathematics curriculum. In M. Grove, T. Croft, J. Kyle & D. Lawson (Eds.), *Transitions in Undergraduate Mathematics Education* (pp. 173-189). Birmingham, U.K.: University of Birmingham.

Gardner, M. (1959). *The Scientific American Book of Mathematical Puzzles and Diversions*. New York: Simon and Schuster.

Gough, J. (2015). New games that stimulate mathematical thinking. *The Australian Mathematics Teacher*, vol. 71(1), 24-27.

Lawson, D. (2015). Mathematics Support at the transition to university. In M. Grove, T. Croft, J. Kyle & D. Lawson (Eds.), *Transitions in Undergraduate Mathematics Education* (pp. 39-56). Birmingham, U.K.: University of Birmingham.

QAA [The Quality Assurance Agency for Higher Education] (2015). *Subject Benchmark Statement: Mathematics, Statistics and Operational Research*. Gloucester, U.K.: The Quality Assurance Agency for Higher Education.

Rowlett, P. (2015). Developing Strategic and Mathematical Thinking via Game Play: Programming to Investigate a Risky Strategy for Quarto. *The Mathematics Enthusiast*, vol. 12(1, 2 & 3), 55-61.

Trowler, V. & Trowler, P. (2010). *Student engagement evidence summary*. York, U.K.: The Higher Education Academy.

Webster, K. & Rowlett, P. (2013). A Maths Arcade at Nottingham Trent University. *Mathematics Today*, vol. 49, 120.